

Announcements

□ EXAM 3 will be *this* Thursday!

□ Homework for tomorrow...

Ch. 34: CQ 8 & 10, Probs. 26 & 58

CQ8: a) left to right b) zero c) right to left

33.30: $2.6 \times 10^{-4} \text{ V}$

33.34: $8.6 \times 10^{-4} \text{ A}$

□ Office hours...

MW 10-11 am

TR 9-10 am

F 12-1 pm

□ Tutorial Learning Center (TLC) hours:

MTWR 8-6 pm

F 8-11 am, 2-5 pm

Su 1-5 pm

Chapter 34

Electromagnetic Fields & Waves *(Properties of EM Waves & Polarization)*

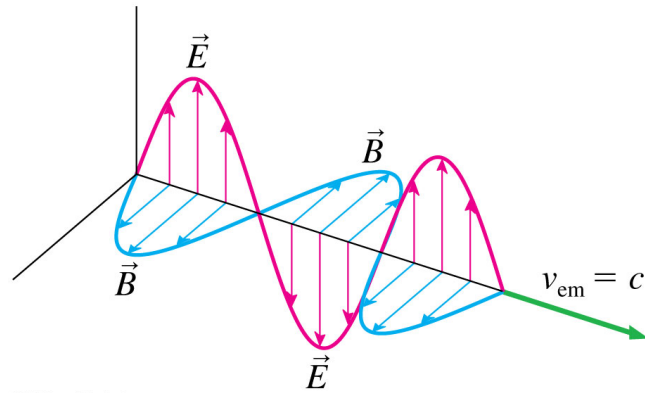
Last time...

The EM wave *amplitudes* are related by...

$$E_0 = cB_0$$

The EM wave *speed*, in vacuum, is...

$$v_{em} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \simeq 3.0 \times 10^8 \text{ m/s}$$



The Poynting vector is...

$$\vec{S} \equiv \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

Energy & Intensity

- The Poynting vector is a function of time, oscillating from 0 to S_{max} and back to 0 *twice* during each period of the wave's oscillation.
- Of more interest is the *average* energy transfer, averaged over one cycle of oscillation, which is the wave's *intensity*.
- The *intensity* of the *EM* wave is...

Energy & Intensity

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- The *intensity* of the *EM* wave is...

$$I = \frac{P}{A} = \frac{1}{2c\mu_0} E_0^2 = \frac{1}{2} c\epsilon_0 E_0^2$$

Energy & Intensity

- The *intensity* of a wave fall off with distance.
- If a *point source* with power P_{source} emits *EM* waves *uniformly* in all directions, the *EM* wave intensity at distance r from the source is

$$I = \frac{P_{source}}{4\pi r^2}$$

Quiz Question 1

To *double* the intensity of an EM wave, you should increase the amplitude of the electric field by a factor of

1. 0.5.
2. 0.707.
3. 1.414.
4. 2.
5. 4.

i.e. 34.4:

Fields of a cell phone

A digital cell phone broadcasts a 0.60 W signal at a frequency of 1.9 GHz.

What are the amplitudes of the E - and B -fields at a distance of 10 cm, about the distance to the center of the user's brain?

Radiation Pressure...

EM waves transfer not only *energy* but also *momentum*.

- Suppose we shine a beam of light on an object that *completely absorbs* the light energy.
- The *radiation pressure* on the surface is...

Radiation Pressure...

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$$p_{rad} = \frac{I}{c}$$

where I is the *intensity* of the light wave.

Notice: p_{rad} is *radiation pressure* NOT *momentum*!

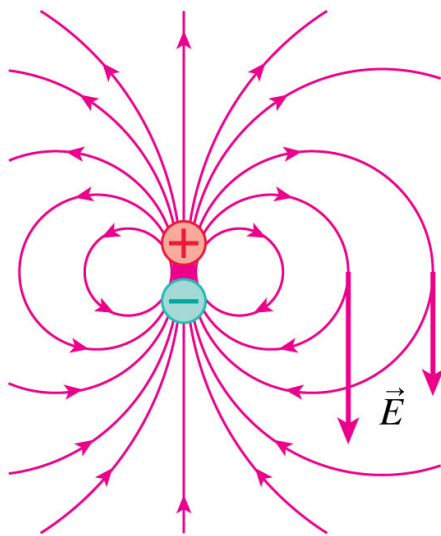
i.e. 34.5: Solar Sailing

A low-cost way of sending spacecraft to other planets would be to use the radiation pressure on a solar sail. The intensity of the sun's EM radiation at distances near earth's orbit is about 1300 W/m^2 .

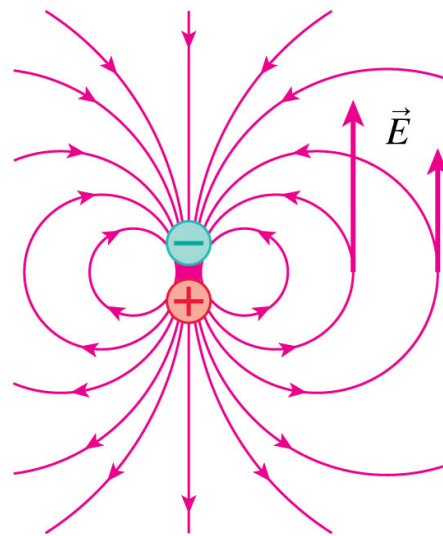
What size sail would be needed to accelerate a $10,000 \text{ kg}$ spacecraft toward Mars at 0.010 m/s^2 ?

Antennas...

- An electric dipole creates an E -field that *reverses direction* if the dipole charges are switched.
 - An oscillating dipole can *generate* an EM wave.



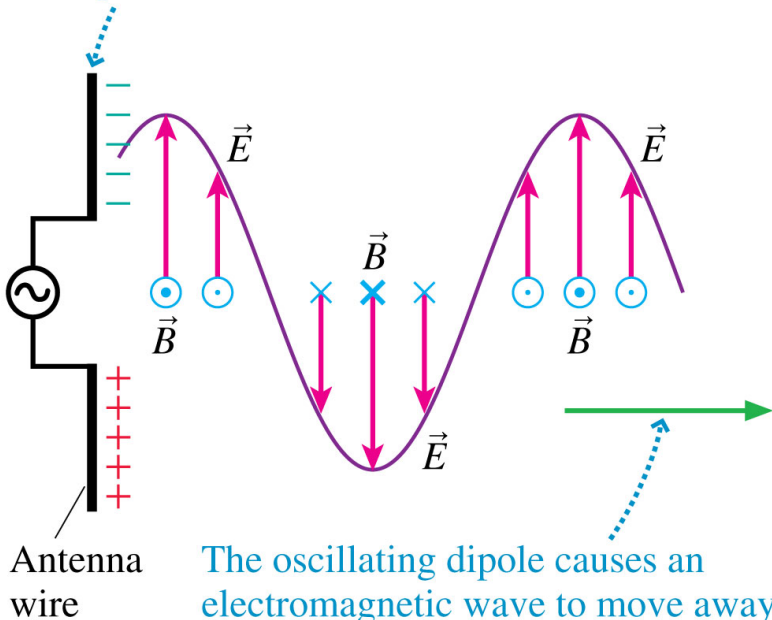
Positive charge on top



Negative charge on top

Antennas...

An oscillating voltage causes the dipole to oscillate.

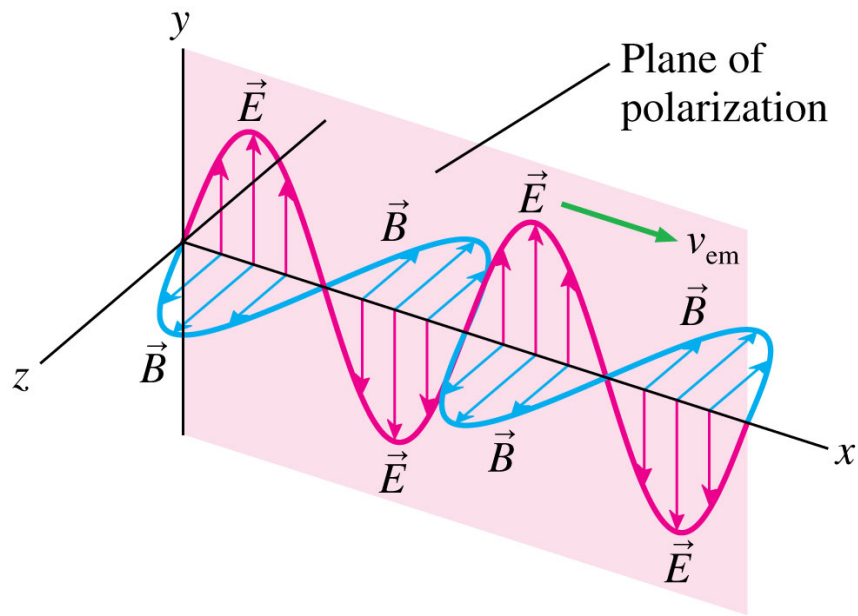


The oscillating dipole causes an electromagnetic wave to move away from the antenna at speed $v_{\text{em}} = c$.

- An antenna acts like an *oscillating electric dipole*, involving both moving charge and a current.
- A self-sustaining EM wave is produced!

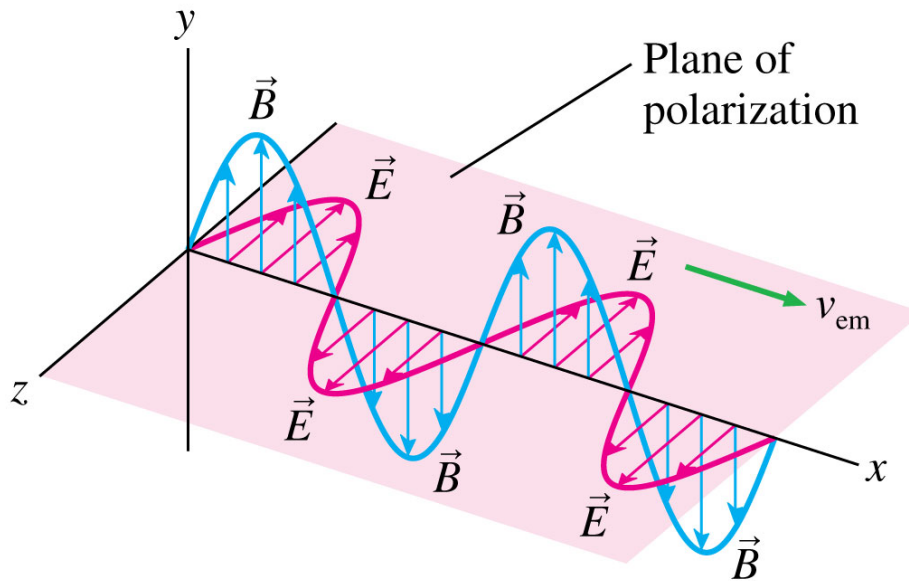
34.7: Polarization

- The plane of the E -field vector & the Poynting vector, S , is called the *plane of polarization*.
- The E -field in the figure below oscillates vertically, so this wave is *vertically polarized*.



34.7: Polarization

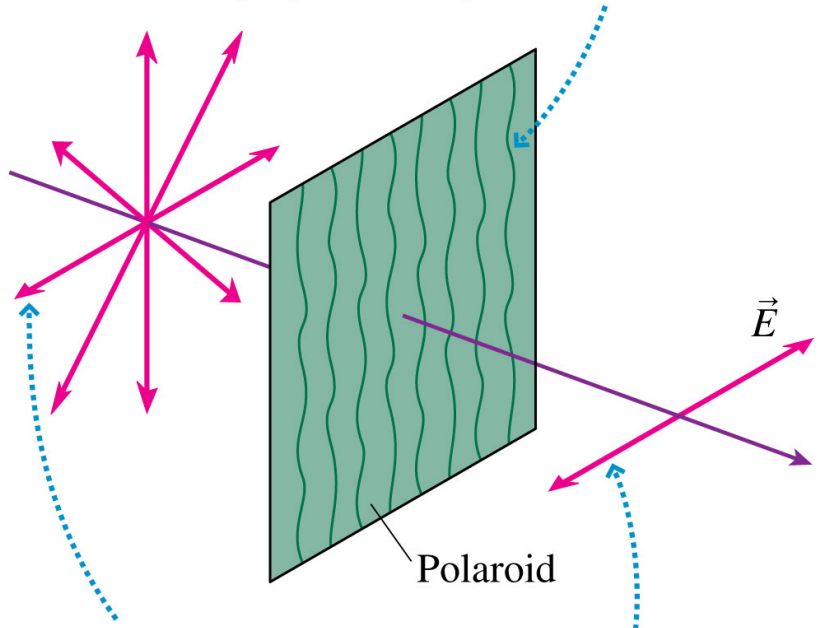
The E -field in the figure below is *horizontally polarized*...



- Most natural sources of light are *unpolarized*, emitting waves whose E -fields oscillate *randomly* with ALL possible orientations.

34.7: Polarization

The polymers are parallel to each other.



The electric field of unpolarized light oscillates randomly in all directions.

Only the component of \vec{E} perpendicular to the polymer molecules is transmitted.

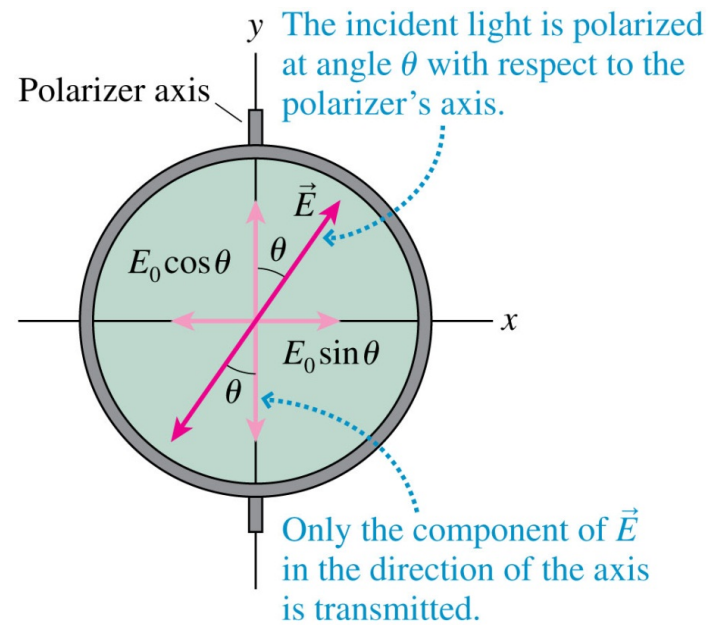
To polarize unpolarized light, send it through a polarizing filter.

Malus's Law

Consider *polarized* light of intensity I_o approaching a *polarizing filter*...

The component of the E -field that is polarized *parallel* to the axis is *transmitted*.

- The *transmitted intensity* is...



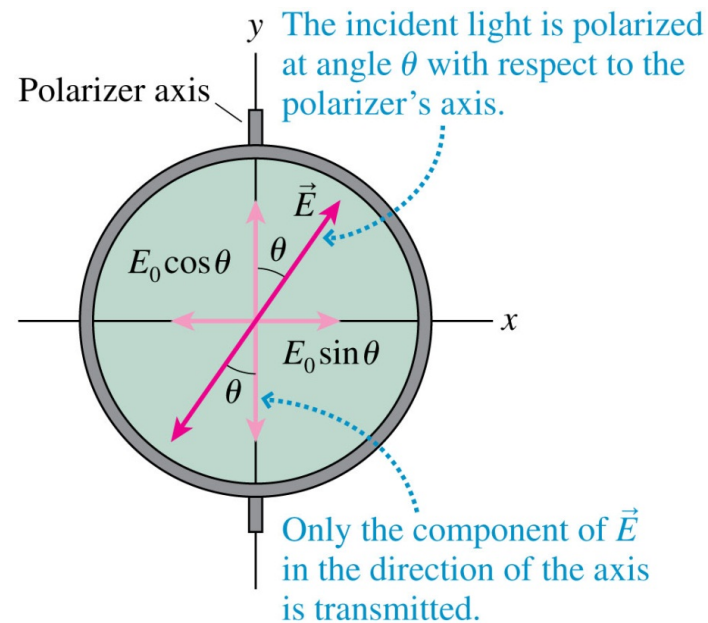
Malus's Law

Consider *polarized* light of intensity I_0 approaching a *polarizing filter*...

The component of the E -field that is polarized *parallel* to the axis is *transmitted*.

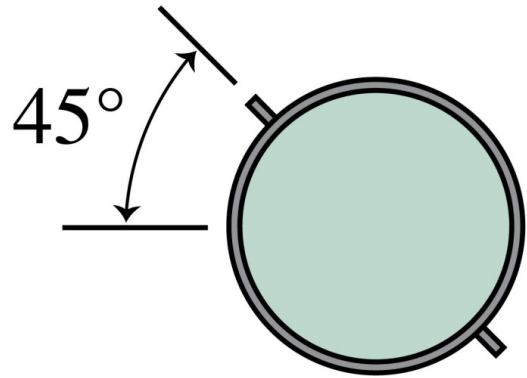
- The *transmitted intensity* is...

$$I_{trans} = I_0 \cos^2 \theta$$



Quiz Question 2

A vertically polarized light wave of intensity 1000 mW/m^2 is coming toward you, out of the screen. After passing through this polarizing filter, the wave's intensity is

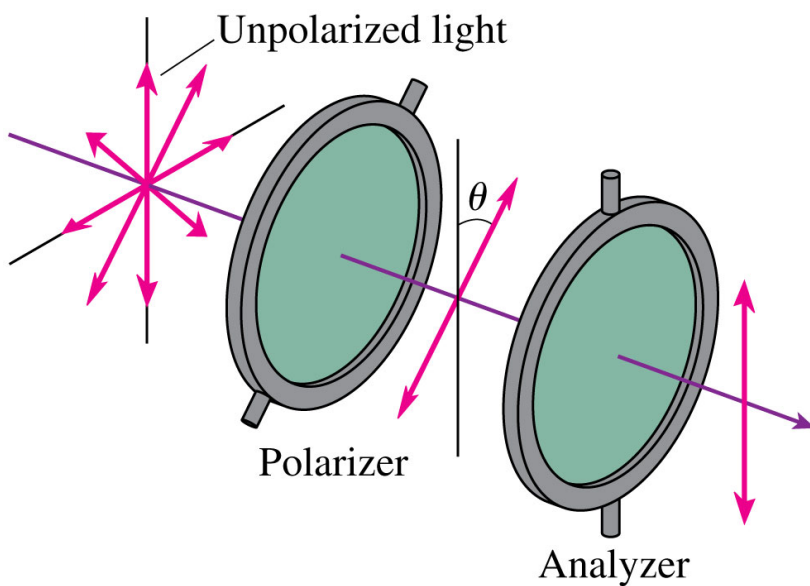


1. 707 mW/m^2 .
2. 500 mW/m^2 .
3. 333 mW/m^2 .
4. 250 mW/m^2 .
5. 0 mW/m^2 .

Polarizers and Analyzers...

Malus's law can be demonstrated with two polarizing filters...

- The first, called the *polarizer*, is used to produce polarized light of intensity I_o .



The second, called the *analyzer*, is rotated by angle θ relative to the polarizer.